Novel approach for calibration breakdown voltage of large area SiPM

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International Workshop on New Photon-Detectors: PhotoDet 2012
June 13-15, 2012 – LAL Orsay, France

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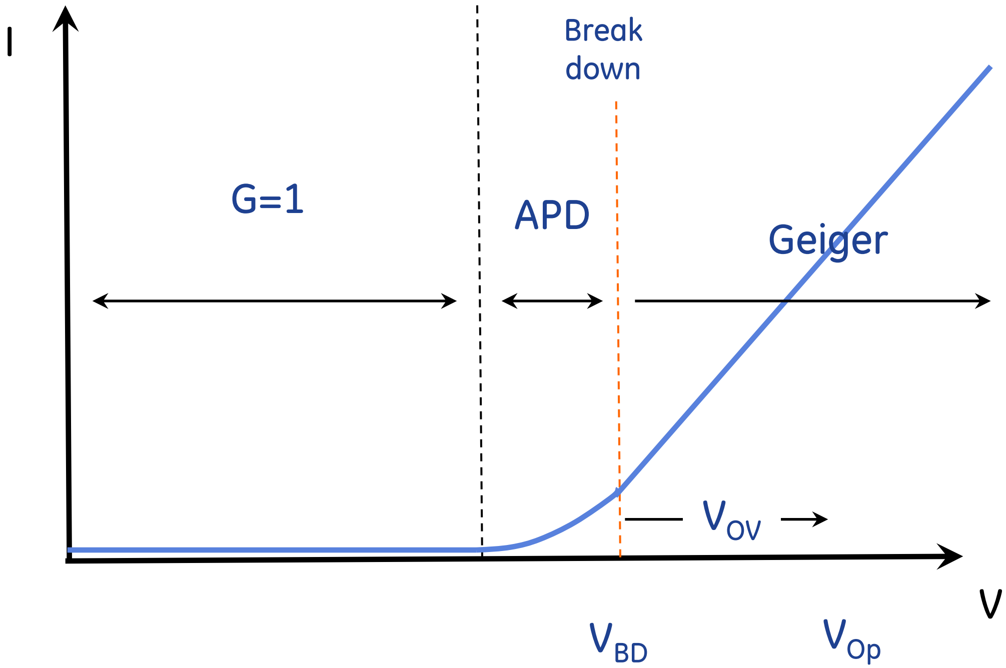
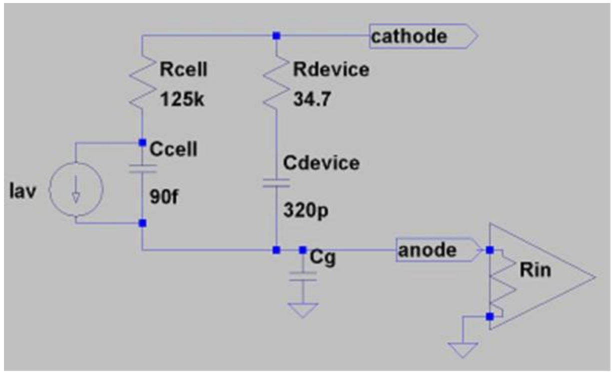
Geiger Mode APD and Gain

Operation principle: Photodiode-> APD ->Break down -> Geiger

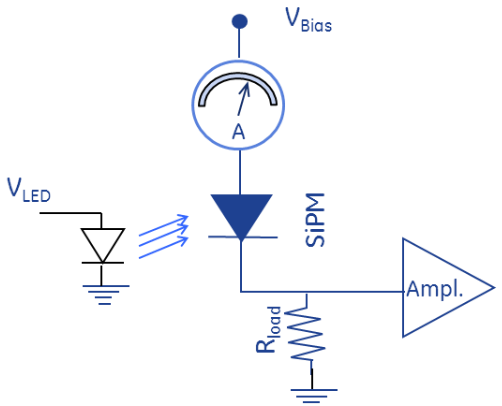




$$Gain_{Geiger} = V_{OV}*C_{diode}$$

DC vs. pulsed Gain Calibration

Gain definition	Diode, Gain1	APD, Gain <1000	Geiger Mode APD, Gain ~10^5-10^6
	Gain 1, QE measurement	Linear mode: QE and Gain(V)	Geiger mode, with limited N_{cells} $PDE(V_{ov})$, $Gain(V_{ov})$
DC	OK	OK, dark current contribution is small	Difficult: After pulses and Crosstalk
Pulsed mode	Slow pulse, low noise, low bandwidth amplifier	Medium intensity light pulse	~1 SPE per pulse. Need high gain, low noise amplifier



Linear - PMT, PIN diode or APD

$$Signal = N_{Ph} * QE * Gain$$

SiPM

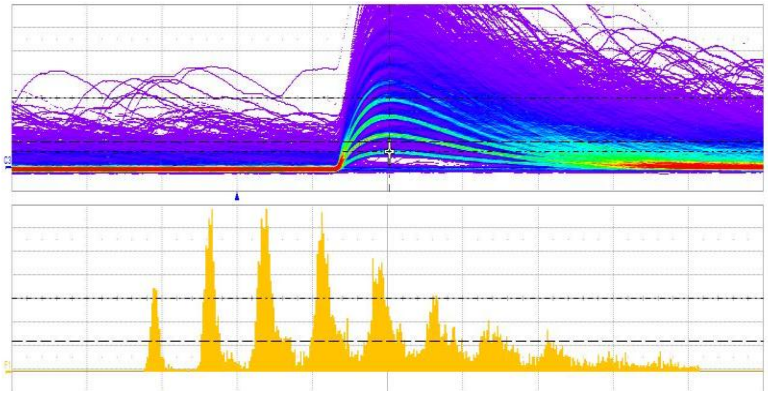
$$Signal = N_{Ph} * QE * P_{Geiger} * G_{SPE}$$

$$P_{Geiger}(V_{ov}, N_{ph}/N_{cells})$$

Need high gain, low noise amplifier or different method

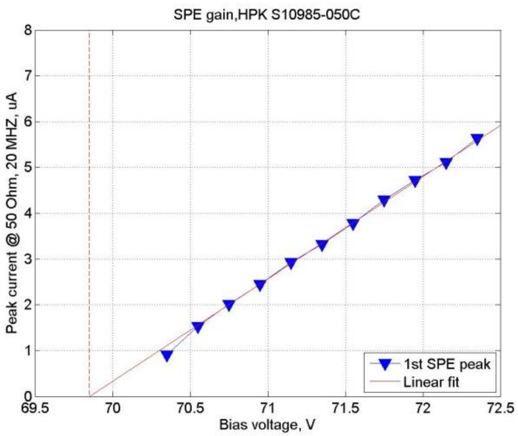
SPE based calibration

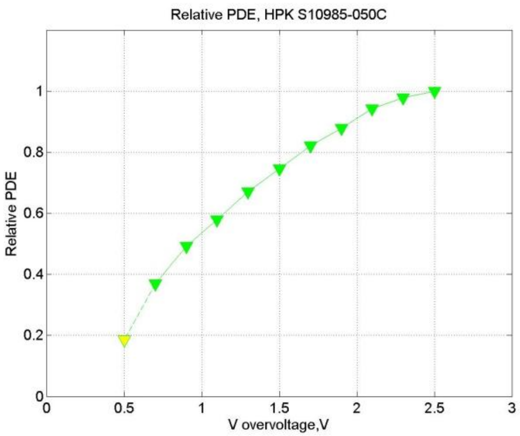
- Works very well for small devices ~1-10 mm^2
- Can use non-calibrated light source
- Need for PDE vs. V_{ov} measurements
- Need high gain, low noise amplifier



MPPC – S10985-050C SN#407, 3x3 mm^2

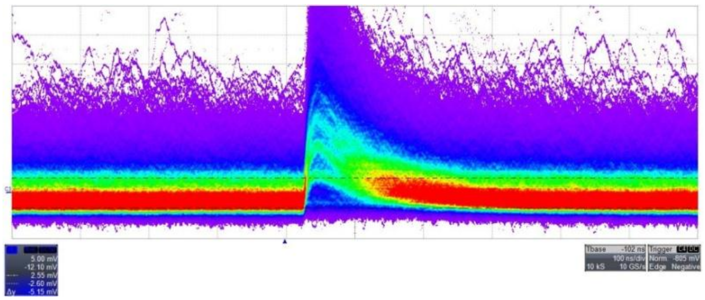
- MPPC – S10985-050C SN#407, 3x3 mm^2
- Laser 405 nm PicoQuant LDH-D-C-405, 3.3 mW @ 40 MHz
- 10 kHZ , attenuated OD 4.0
- Preamp. 50 Ohm,
- Oscilloscope LeCroy WaveRuner 610Zi 1 GHz , filter -BW 20 MHZ





SPE based calibration

- Works very well for small devices ~1-10 mm^2 with low noise
- Need high gain, low noise amplifier
- Problematic for big devices ~10-100 mm^2 : Long recharging time, high dark count rate, crosstalk and after pulses make it difficult



MPPC – S10985-050C SN#407, 4 x 3x3 mm^2

3x3 mm^2 -> 6x6 mm^2

MPPC-50um intrinsic impedance

35 Ohm+320 pF -> 9 Ohm+1500 pF

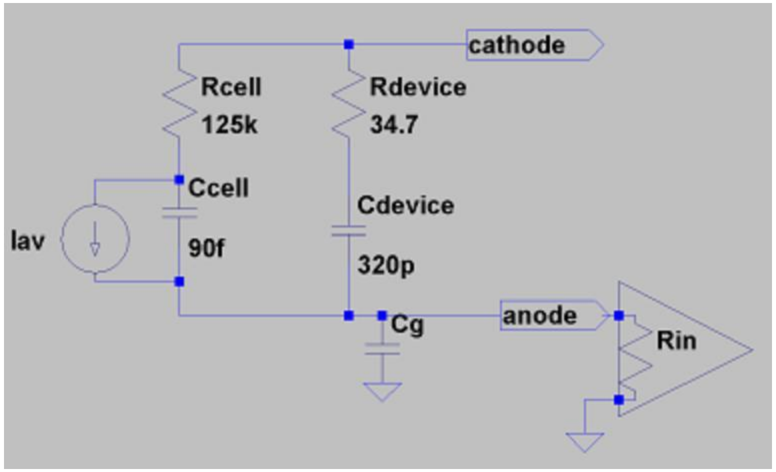
Recovery time

$\tau = C_{SiPM}*(R_{SiPM}+R_{Input})$

τ = 27 ns -> τ = 75 ns, @50 Ohm

1 SPE, V_{ov}=1 V @50 Ohm

V_{peak} = 165 uV -> V_{peak} = 60 uV.



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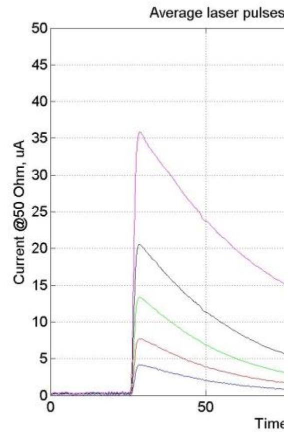
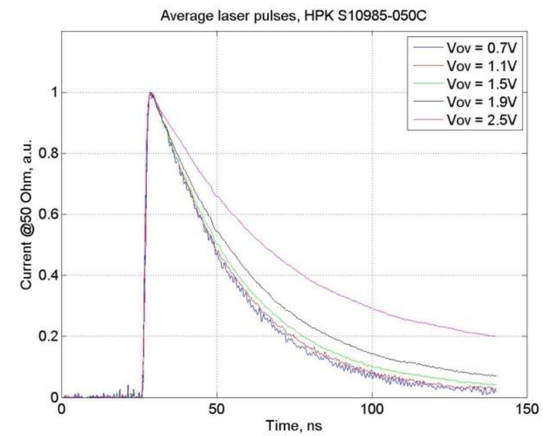
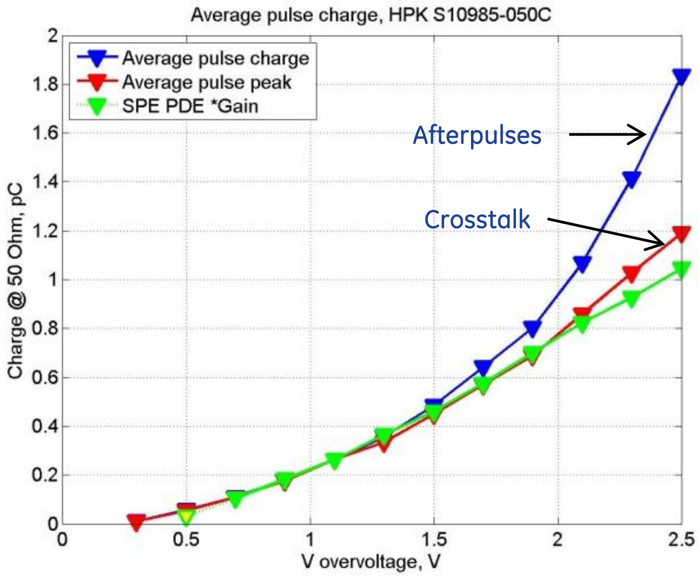
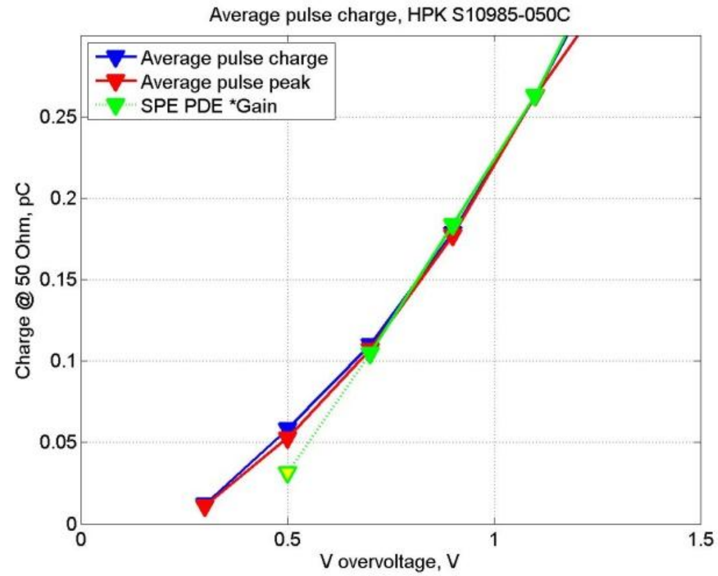
Average pulse based calibration

- Measure average pulse amplitude and charge vs. V_{bias} for ~10-100 SPE
- Fast method
- Pulse shape is the same as SPE pulse shape
- Measure PDE*G_{SPE} *(1+Xtalk)
- Non-linear behavior in V_{br} region -> difficult to interpolate







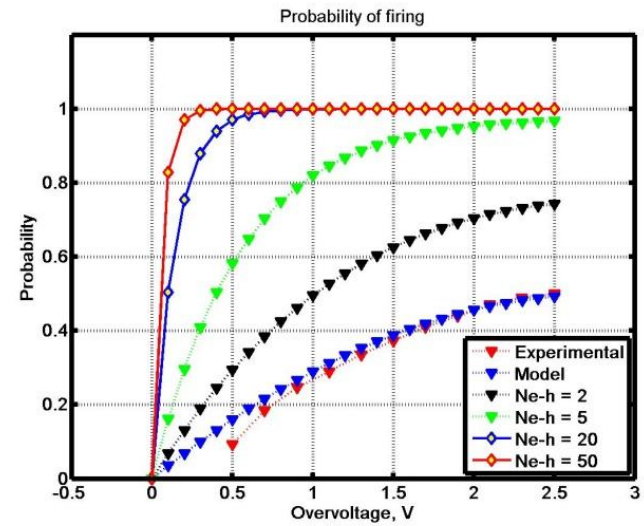


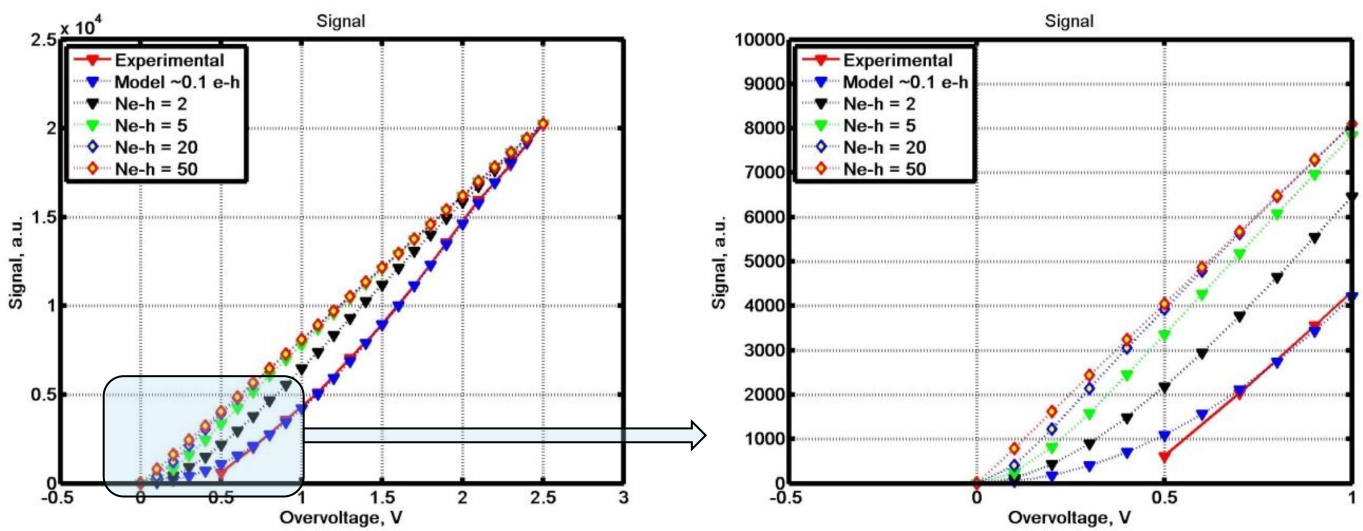
“High intensity” pulsed calibration

Let’s trigger all cells by HUGE light pulse

$PDE(N_{ph})\sim 1-\exp(-P_{Geiger}*N_{ph}/N_{cells})$

- No PDE dependence
- Signal is linear for small V_{ov}





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“High intensity” pulsed calibration

Optical power requirements:

$$E_{pulse} = E_{ph}(\lambda)*N_{e\text{-}h}/QE*N_{cells}*Area_{Illuminated}/Area_{SiPM}$$

For 1 cm^2 illuminated area and 50 um u-cell

$$E_{pulse}(405\ nm) = 1.2\ pJ$$

1 ns pulse $PeakPower_{Optical}(405) = 1\ mW$

PicoQuant LDH-D-405 ~50-60 pJ /pulse

Laser Diodes ~100mW available

- Use SiPM below V_{br} to measure pulse intensity
- $I(G=1) = F_{rep}*N_{cells}*N_{e\text{-}h}*Q_e = 10\ kHz*3600*30*1.6e\text{-}19 = 180\ pA$

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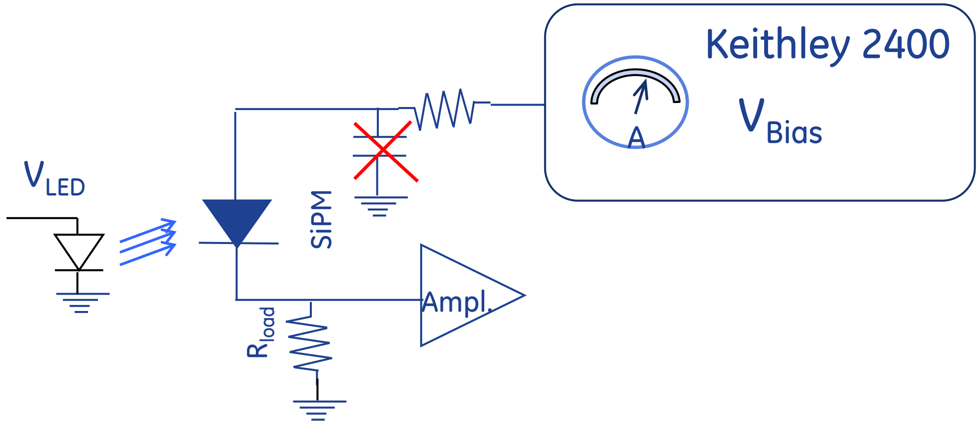
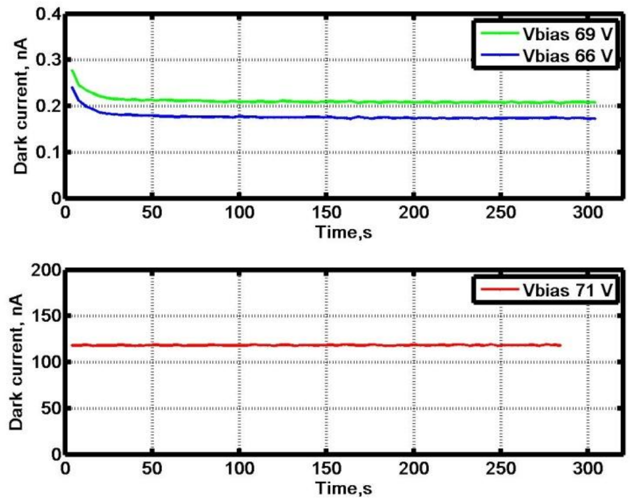
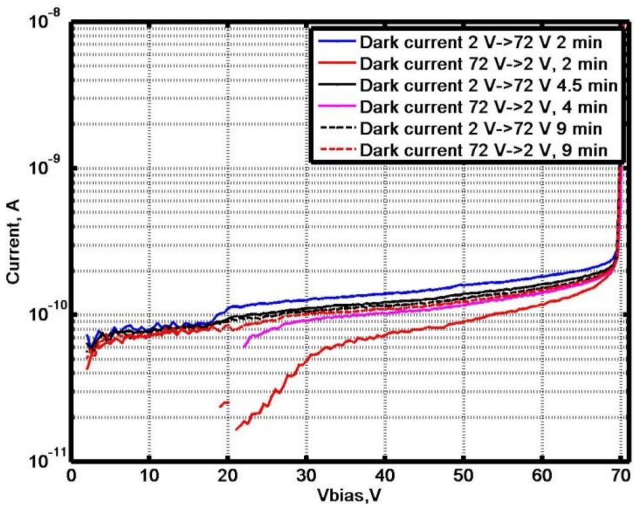
Dark current measurement

- Keithley 2400 SourceMeter I-V measurements:
- How fast to do I-V scan?
  - Remove C from V_{bias} (RC, leakage ~nA) !
  - SiPM stabilization time ~10 sec

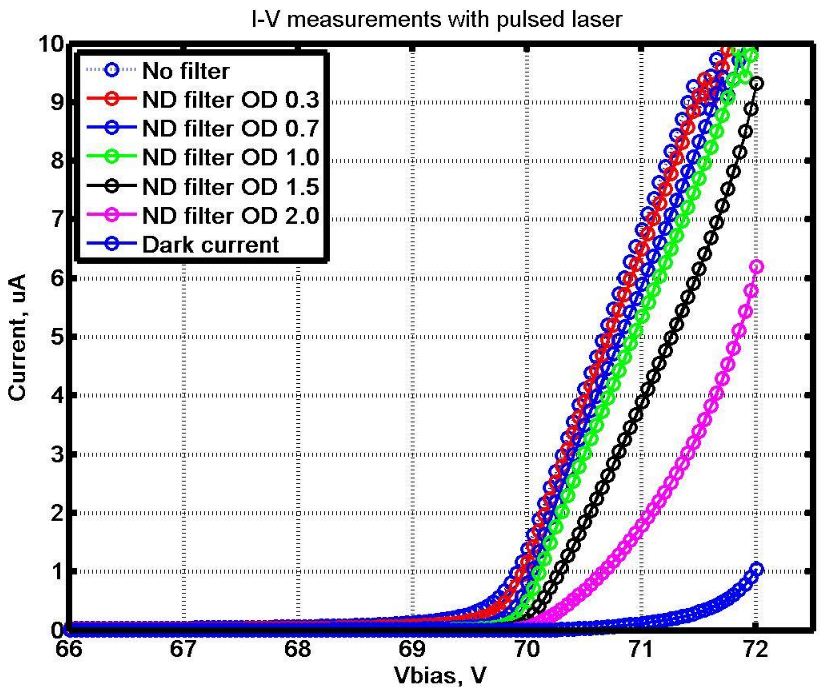


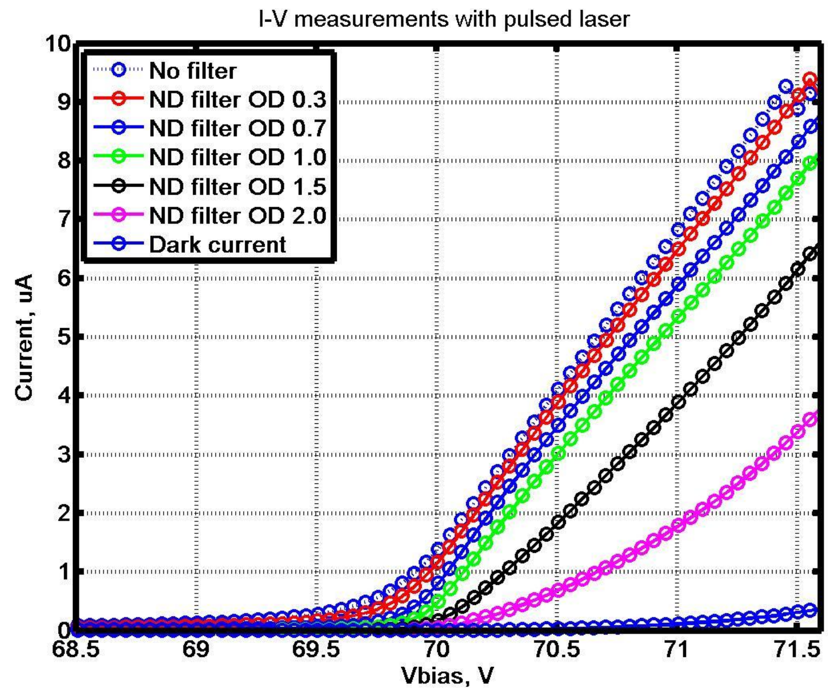




“High intensity” pulsed calibration

- MPPC – S10985-050C SN#407, 3x3 mm^2
- Laser 405 nm PicoQuant LDH-D-C-405, 3.3 mW @ 40 MHz
- 10 kHZ , attenuated OD 0 - 2.0





For wide range of light intensity I-V has linear part

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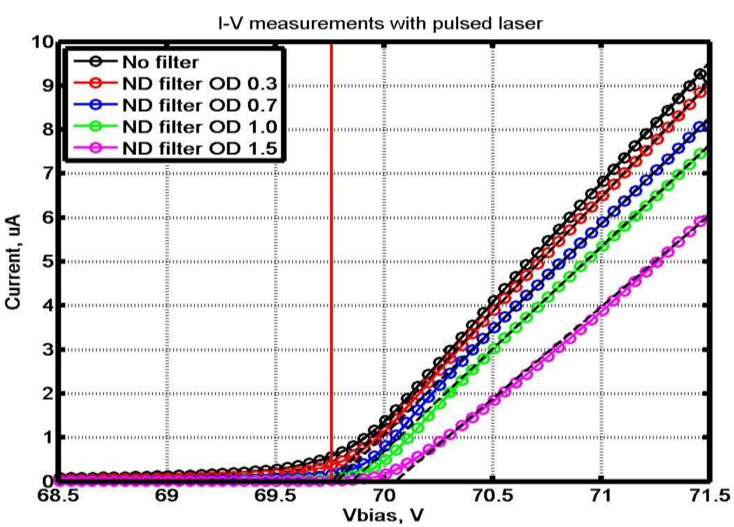
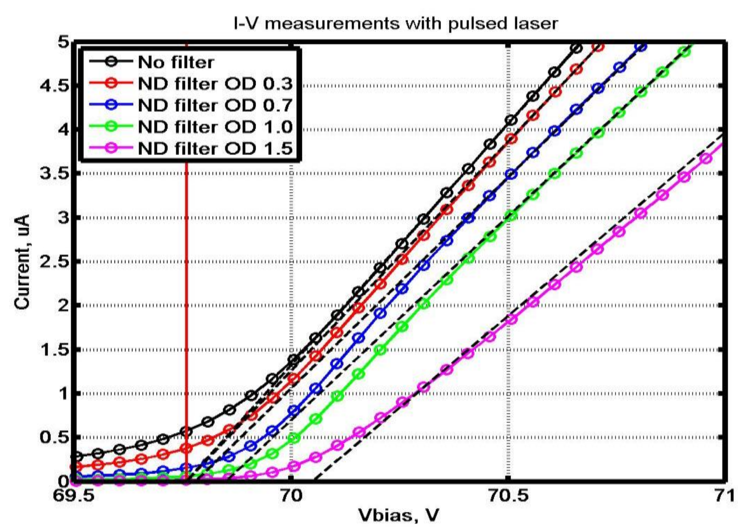
"High intensity" pulsed calibration

$$Gain/dV = dI/dV/F_{rep}/N_{cell} = C_{diode}$$

	I diode	e-h/ucell	Gain/dV	V_{br}
No filter	4.5 nA	800	152 fF	69.76
ND 0.3	2.4 nA	420	145 fF	69.76
ND 0.7	0.8 nA	140	132 fF	69.78
ND 1.0	0.28 nA	50	122 fF	69.85
ND 1.5	0.07 nA	12	97 fF	70.05





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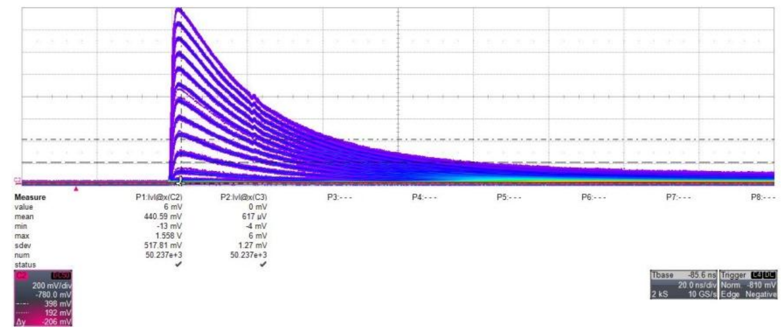
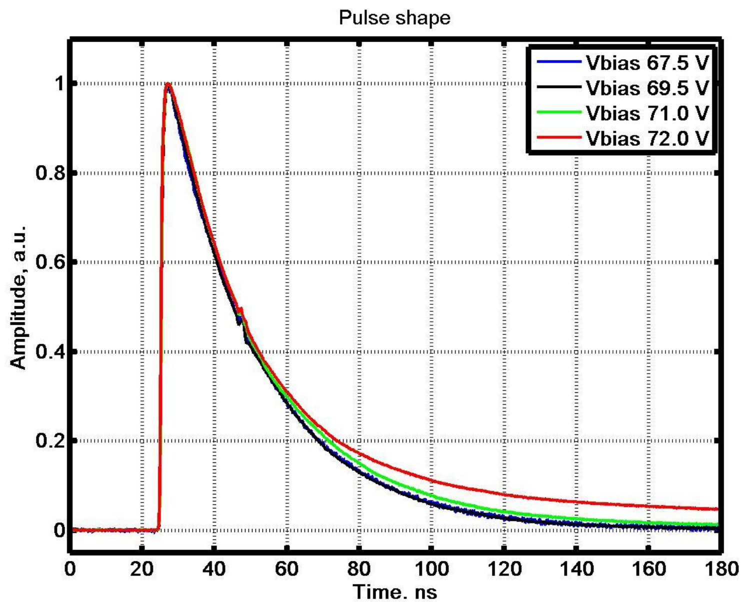
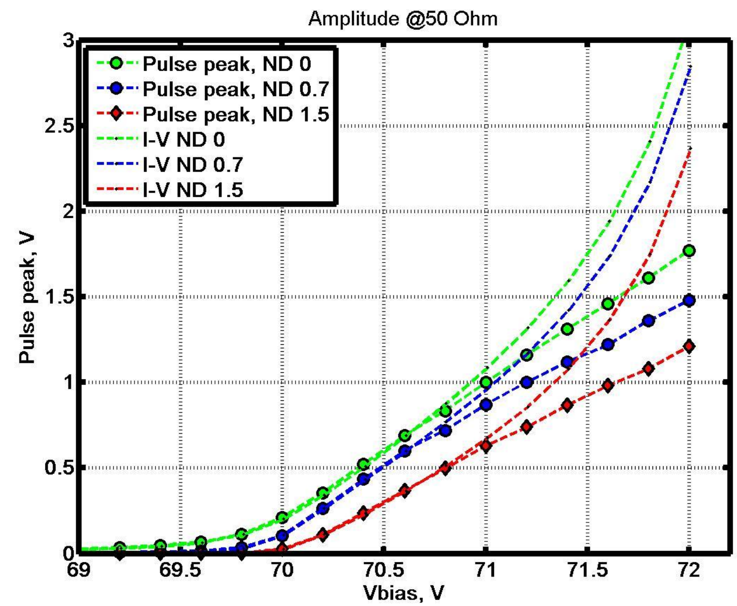
“High intensity” pulsed calibration

Amplitude @ 50 Ohm = Vov* 50/(R_{SiPM} +50)

	e-h/ucell	Slope	Gain/dV
No filter	800	0.9	152 fF
ND 0.7	140	0.75	132 fF
ND 1.5	12	0.6	97 fF



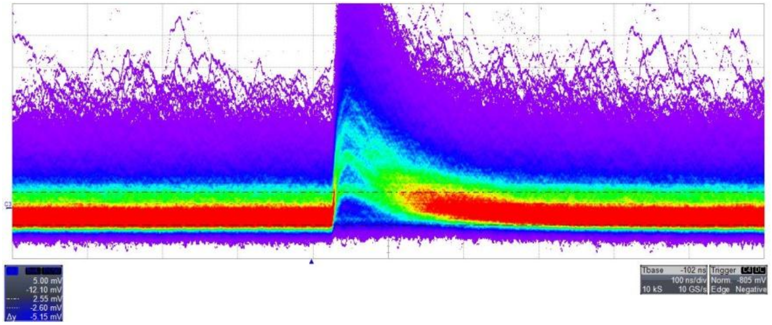


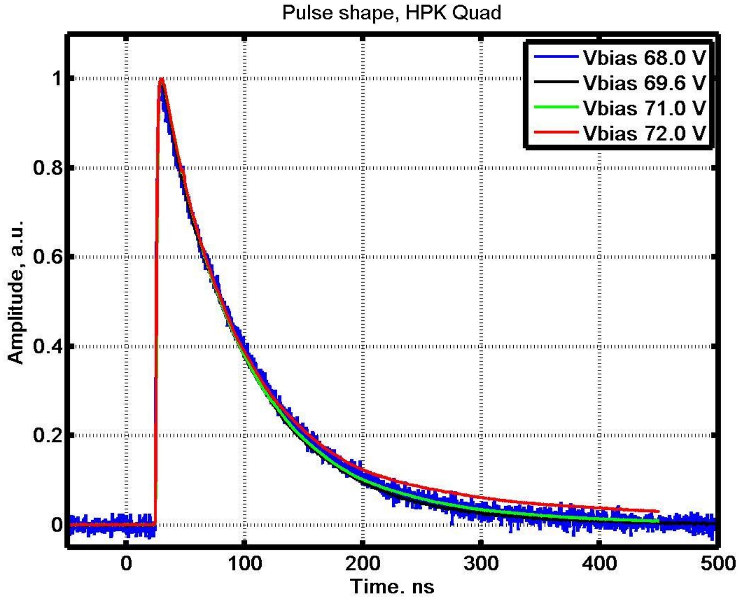


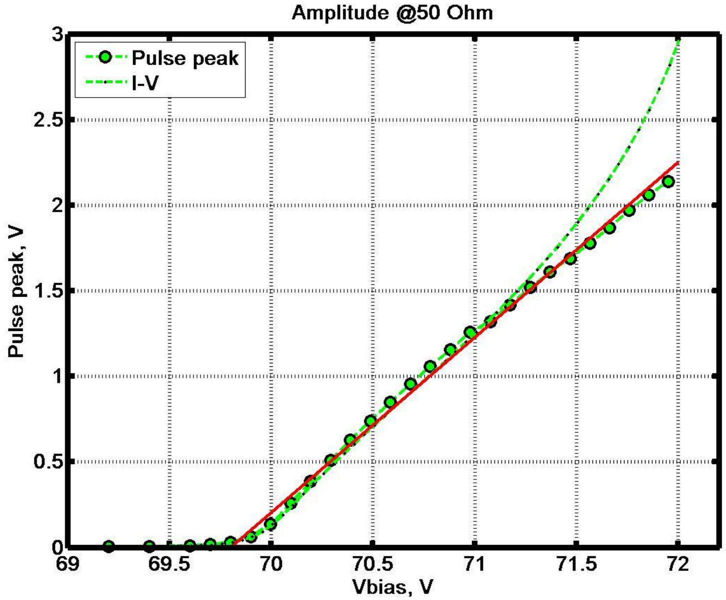
"High intensity" pulsed calibration HPK 6x6 mm^2

Amplitude @ 50 Ohm = Vov* 50/(R$_{SiPM}$ +50)

	e-h/ucell	Slope	Gain/dV
Laser spot ~5 cm^2	30	1.0	129 fF







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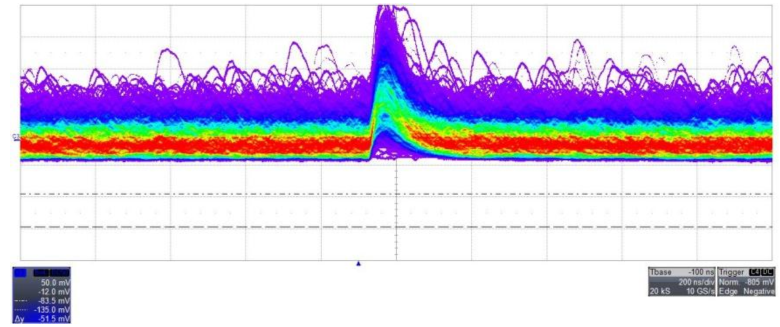
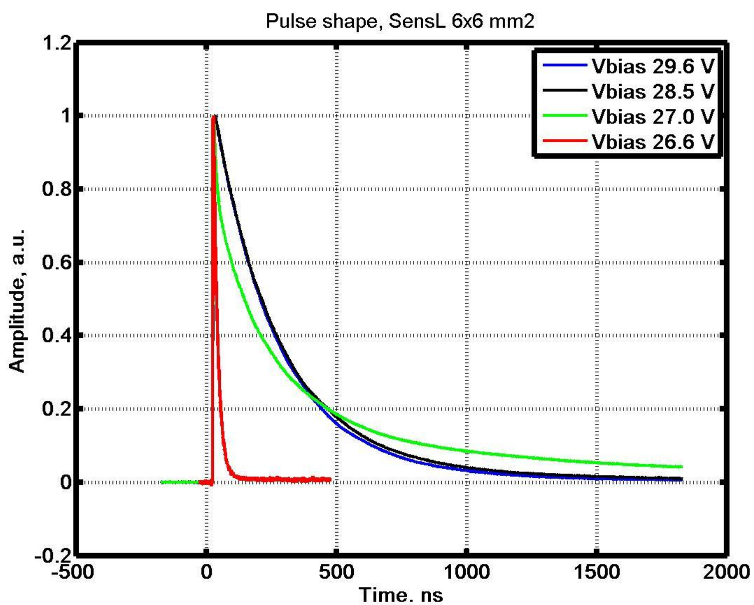
“High intensity” pulsed calibration SensL 6x6 mm^2

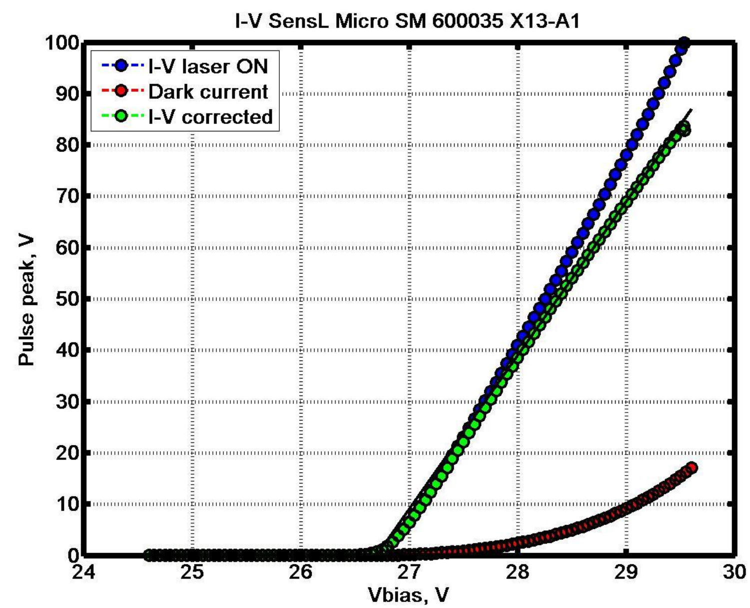
Amplitude @ 50 Ohm = Vov* 50/(R_{SiPM} +50)

	e-h/ucell	Slope	Gain/dV
Laser spot ~5 cm^2	10	0.58	158 fF

SensL Micro SM 60035-X13 Lot 11-100



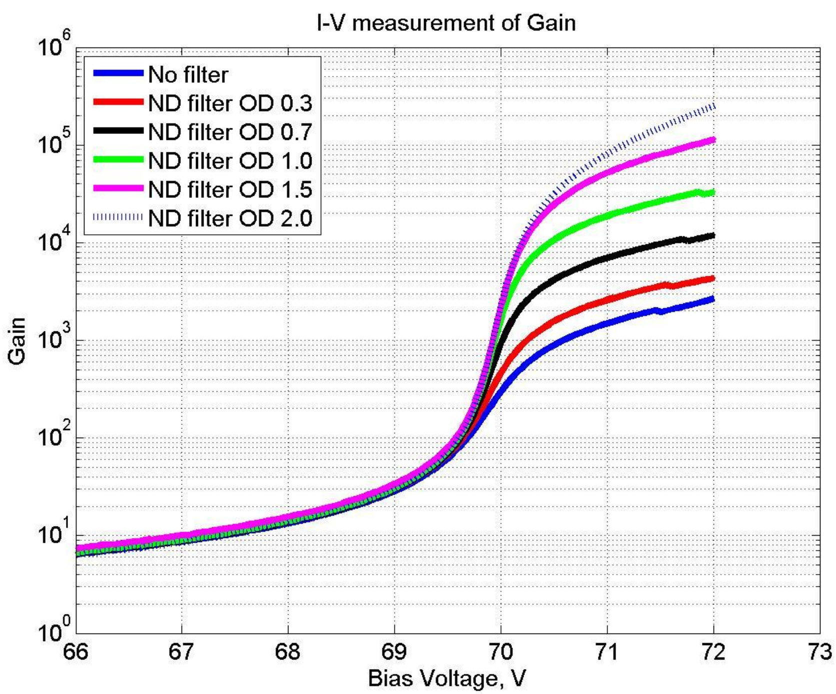


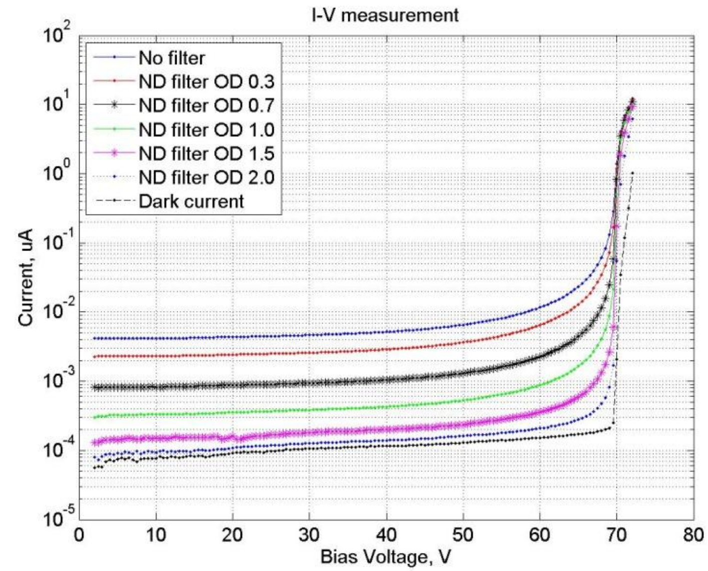


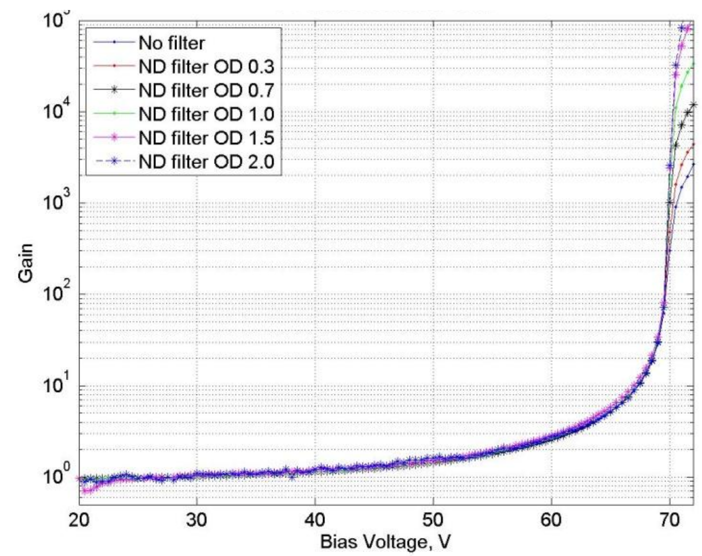
SiPM as APD

$$Gain = (I - I_{dark})/(I_{27V} - I_{dark,27V})$$

- SiPM works as APD
- Limited linearity
- Gain ~1000 at V_{br}







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Conclusion

- The High Intensity pulse calibration method is simple and reproduces V_{br} measured by SPE
- I-V measurement can be used during SiPM production
- No need of a high gain amplifier, can be used with FE electronics optimized for scintillator pulses
- SiPM can operate as an APD below break down
- Simple model of SiPM and Geiger avalanche development does not work for very high number of primary e-h